

*PAVLOVIAN CONTINGENCIES AND RESISTANCE TO
CHANGE IN A MULTIPLE SCHEDULE*

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According to theoretical accounts of behavioral momentum, the Pavlovian stimulus–reinforcer contingency determines resistance to change. To assess this prediction, 8 pigeons were exposed to an unsignaled delay-of-reinforcement schedule (a tandem variable-interval fixed-time schedule), a signaled delay-of-reinforcement schedule (a chain variable-interval fixed-time schedule), and an immediate, zero-delay schedule of reinforcement in a three-component multiple schedule. The unsignaled delay and signaled delay schedules employed equal fixed-time delays, with the only difference being a stimulus change in the signaled delay schedule. Overall rates of reinforcement were equated for the three schedules. The Pavlovian contingency was identical for the unsignaled and immediate schedules, and response–reinforcer contiguity was degraded for the unsignaled schedule. Results from two disruption procedures (prefeeding subjects prior to experimental sessions and adding a variable-time schedule to timeout periods separating baseline components) demonstrated that response–reinforcer contiguity does play a role in determining resistance to change. The results from the extinction manipulation were not as clear. Responding in the unsignaled delay component was consistently less resistant to change than was responding in both the immediate and presignaled segments of the signaled delay components, contrary to the view that Pavlovian contingencies determine resistance to change. Probe tests further supported the resistance-to-change results, indicating consistency between resistance to change and preference, both of which are putative measures of response strength.

Key words: behavioral momentum theory, resistance to change, Pavlovian versus operant contingencies, multiple schedules, key peck, pigeons

Resistance to change is a measure of the persistence of responding when disruptive variables are introduced into a steady-state conditioning paradigm. It is assessed by observing behavior changes resulting from manipulations intended to decrease, or disrupt, behavior when imposed over a steady-state baseline. The usual procedure for studying resistance to change is a multiple schedule of reinforcement (see Nevin, 1992, for a review), in which two reinforcement schedules alternate in some fashion until responding has stabilized.

Nevin (1992) has used the behavioral momentum metaphor to characterize the relationship between two independent aspects of behavior, resistance to change (analogous to behavioral mass) and response rate (analogous to velocity). Nevin argued that differ-

ences in behavioral mass are reflected by changes in response rate (i.e., resistance to change) by imposing an external force across separate components. External force can be imposed on the baseline behavior in a variety of ways, all of which should yield similar results. The most typical methods involve (a) feeding subjects prior to the experimental session, (b) adding free food, usually in the form of a variable-time (VT) schedule presented during timeout periods separating baseline components of the multiple schedule, and (c) extinction of the baseline components. Resistance to change is assessed by calculating the ratio of response rate during disruption to the response rate preceding baseline. Normalizing the data in this way allows comparison between schedules with unequal baseline response rates.

The most comprehensive version of behavioral momentum theory (Nevin, 1992) argues that resistance to change is an alternative measure of response strength, complementing Herrnstein's (1970) quantitative model of the relationship between response rate and reinforcer rate. Nevin proposed that Herrnstein's model describes how response rate is determined, namely by the operant contin-

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gencies, and behavioral momentum theory describes how response strength is determined, namely by the relationship between a stimulus and the reinforcement delivered in the context of that stimulus (the Pavlovian contingency). Behavioral momentum theory has successfully integrated several different disruption procedures, all of which yield similar results. Nevin concluded from the data that resistance to change is solely determined by Pavlovian contingencies.

Behavioral momentum theory is a relatively new approach to the study of response strength, and the assertion that resistance to change, and therefore response strength, is determined by Pavlovian contingencies has not been extensively tested. Although the existing data do generally support this assertion, it is still not clear that Pavlovian contingencies are the sole determiners of resistance to change. It is also unclear what relationship, if any, exists between resistance to change and the more traditional measures of response strength, namely response rate and preference.

Although changes in response rate are used as the dependent measure, there is evidence that resistance to change is independent of response rate. Nevin (1992; see his Figure 1) provided evidence for the separation of response rate and resistance to change by comparing two studies. The first (Nevin, Mandell, & Atak, 1983) presented pigeons with a multiple schedule using variable-interval (VI) reinforcement schedules. Although reinforcement rates differed dramatically (129 per hour vs. 42 per hour), baseline response rates were quite similar (85 to 87 responses per minute). Adding a VT schedule during timeouts revealed that resistance to change was quite different for the two schedules. Responding maintained by the 129 reinforcers per hour schedule was considerably more resistant to change than was responding maintained by the 42 reinforcers per hour schedule. The second study (Fath, Fields, Malott, & Grossett, 1983) presented pigeons with two schedules of reinforcement with equal reinforcement rates (60 per hour) but different response rates (approximately 28 responses per minute in one component and 70 responses per minute in the other), again using a multiple schedule. Differential-reinforcement-of-high-rate (DRH) and differ-

ential-reinforcement-of-low-rate (DRL) schedules were used to obtain this difference in baseline response rates. A VT schedule of reinforcement was presented during the timeouts to disrupt behavior and showed that resistance to change was equal for the two schedules. These two studies provide evidence for dissociation between response rate and resistance to change and an association between reinforcement rate and resistance to change.

Nevin, Tota, Torquato, and Shull (1990) directly tested the independence of the operant contingency and resistance to change. They attempted to assess the role of Pavlovian contingencies by seeing if degrading the response-reinforcer relation independently of the stimulus-reinforcer relation would reduce resistance to change. They trained pigeons on multiple schedules, with equal VI schedules in both components. In one component, free reinforcers were delivered on a VT schedule, thus degrading the response-reinforcer contingency and reducing steady-state responding in that component. Despite the decrement in baseline response rate, greater resistance to extinction and satiation was seen for the VI paired with the added VT schedule than to a comparable VI with no additional sources of reinforcement.

Nevin et al. (1990) replicated these results in a second experiment by pairing a response-dependent VI schedule with one of the baseline VI schedules. The results followed a pattern similar to those of the first experiment, indicating independence between response rate and resistance to change. Based on the evidence from their study, Nevin et al. concluded that resistance to change is determined by stimulus-reinforcer but not response-reinforcer contingencies.

This conclusion opposes traditional theories of response strength that emphasize the response-reinforcer relationship, with delay of reinforcement playing an essential role (see Renner, 1964, and Tarpay & Sawabini, 1974, for reviews). According to such theories, delay of reinforcement is intimately related to the determination of response strength. A large delay of reinforcement implies weak response-reinforcer contiguity, a decrease in response rate, and therefore a decrease in strength. Delays imposed between the terminal response and the reinforcer de-

livery radically disrupt behavior (Williams, 1976), and this has been customarily viewed as indicative of decreased response strength. This disruption in behavior, seen even when small delays occur between a terminal response and the reinforcer delivery, has served as an indication of the critical nature of response–reinforcer contiguity in determining response strength.

The hypothesis that response–reinforcer contiguity affects resistance to change was tested in the present experiment by exposing pigeons to three reinforcement schedules. The first component employed a VI schedule with an unsignaled, nonresetting delay between the terminal response and reinforcer delivery, similar to that used by Williams (1976) and Williams, Preston, and deKervor (1990). The delay did not reset if responses occurred during the delay period, making this a tandem VI fixed-time (FT) schedule of reinforcement. The terminal response was made temporally distant from its consequent reinforcement delivery to disrupt response–reinforcer contiguity while maintaining stimulus–reinforcer and response–reinforcer contingencies.

To interpret the results from the unsignaled schedule procedure, two control schedules were implemented: one that delivered reinforcement immediately following the terminal response and one that signaled the delay between the terminal response and reinforcement. The immediate schedule was a zero-delay schedule of reinforcement employing a simple VI schedule. The signaled delay schedule was identical to the unsignaled delay schedule in that the completion of a VI schedule requirement led to a fixed-time delay to reinforcement, making it a chain VI FT schedule of reinforcement. The delay in the signaled schedule was, however, signaled by a distinct stimulus change that occurred on the response key immediately after the response that satisfied the VI schedule (see Figure 1).

Grace, Schwendiman, and Nevin (1998) used a similar procedure and found less resistance to change for an unsignaled delay when it was compared to a comparable zero-delay component. Specifically, they compared resistance to change across two components of a multiple schedule in which one component imposed a 3-s unsignaled delay to reinforcement and the other component had no

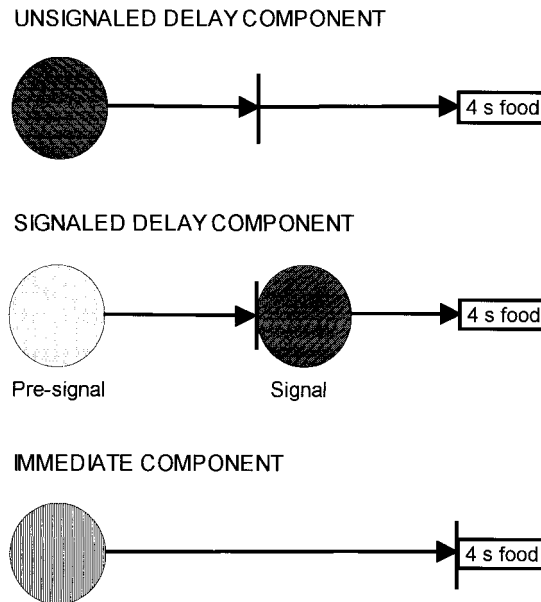


Fig. 1. Procedure illustration. The top portion depicts the unsignaled delay-to-reinforcement component. The vertical line indicates the terminal response satisfying the variable-interval schedule. This results in a non-resetting unsignaled fixed-time delay to reinforcement. The middle panel shows the signaled delay-to-reinforcement component. Notice that it is identical to the unsignaled delay component in that a terminal response (described by the vertical line) results in a fixed-time delay to reinforcement equal to the delay in the unsignaled component. The delay in the signaled component is signaled by a distinct stimulus change on the response key and is illuminated for the duration of the delay. The bottom portion shows the immediate (zero-delay) component. A terminal response satisfying the variable-interval schedule is immediately followed by reinforcement. The overall interreinforcement interval is the same for all three components. Table 1 contains the specific stimulus assignments for each subject.

delay. Reinforcement rates were equal for the two components. Responding to the zero-delay component was more resistant to disruption (prefeeding and extinction) than was responding to the unsignaled delay. In a separate phase, Grace et al. used the unsignaled delay stimulus and the zero-delay stimulus as terminal links in a concurrent-chains procedure and found that subjects preferred the choice alternative leading to the zero-delay terminal link. The results from the two phases showed that resistance to change and preference covaried, in concordance with results from Grace and Nevin (1997).

Given equal reinforcement rates across the three schedule types, the Pavlovian interpre-

tation of momentum predicts that responding under the unsignaled and immediate schedules should be equally resistant to change. Although the response–reinforcer contiguity is degraded for the unsignaled delay schedule, the Pavlovian contingency remains identical to that of the immediate reinforcement schedule. Furthermore, the Pavlovian view of momentum predicts that for the signaled component, presignal (initial-link) stimulus responding should be less resistant to change relative to responding during the signal (terminal-link) stimulus. Regardless of whether behavior to the presignal stimulus is maintained by conditioned reinforcement (although behavioral momentum theory has never been explicitly elaborated to address the role of conditioned reinforcement, it is plausible to expect that conditioned reinforcers function in a similar fashion to primary reinforcers) or a delayed but direct relationship with primary reinforcement, the initial-link stimulus–reinforcer contingency should be weaker than any of the three other stimuli. Nevin, Mandell, and Yarensky (1981) presented pigeons with multiple chained VI VI schedules and found that initial-link responding was consistently less resistant to change than was terminal-link responding.

The present study used three procedures to disrupt behavior: prefeeding prior to experimental sessions, adding a VT schedule in timeout periods separating components, and extinction. A final condition presented probe tests to compare directly resistance to change and preference as measures of response strength. If response strength, as traditionally conceived, is a useful construct, then resistance to change and other traditional measures of response strength should covary. To the degree that they do not, either resistance to change or the other measures must not be measuring the same behavioral effect. In order to be accepted as a valid measure of response strength, resistance to change should covary with more traditional measures of response strength.

METHOD

Subjects

Eight experienced adult pigeons (*Columba livia*) were maintained at 80% of their free-

feeding body weights by additional feeding of pigeon chow, when necessary, at least 1 hr following the end of an experimental session. The mean 80% weight was 460 g, ranging from 405 g to 511 g. All were housed in individual cages with water and grit freely available.

Apparatus

Eight operant chambers were used. Four were identical three-key pigeon operant chambers (36 cm wide, 32 cm long, and 35 cm high), and were used for half of the subjects. In these chambers, all walls were opaque gray plastic except the front, which was sheet aluminum. The right wall (relative to the intelligence panel) contained a small window. Three translucent response keys, 2.5 cm in diameter, were mounted on the front intelligence panel 26 cm above the floor and 7.25 cm apart, center to center. Each key required a force of approximately 0.15 N to operate and could be illuminated from the rear by IEE 28-V 12-stimulus projectors. A 28-V 1-W miniature lamp, located 8.75 cm above the center response key, provided general chamber illumination. Directly below the center key and 9.5 cm above the floor was an opening (5.7 cm high by 5 cm wide) that provided access to a solenoid-operated grain hopper. When activated, the hopper was illuminated from above with white light by a 28-V 1-W miniature lamp. A 5-cm speaker was mounted above the center of the ceiling and provided continuous white noise throughout the experimental sessions.

The remaining four chambers were also equipped with IEE 28-V 12-stimulus in-line projectors and translucent response keys. Directly below the center key was an opening that provided access to a solenoid-operated grain hopper. When activated, the hopper was illuminated from above by a 28-V 1-W miniature lamp. The dimensional and material details regarding these chambers varied, although they were generally similar to the other four chambers.

Speakers located in the four identical chambers, combined with ventilation fans, provided continuous white noise throughout all experimental sessions. The chambers were located in a dark, sound-attenuating room. Experimental events were controlled by IBM-compatible computers (using Intel® 286 mi-

Table 1

Number of sessions for each condition for all pigeons. The conditions are presented in the order in which they were conducted.

Condition	3-s delay to reinforcement				8-s delay to reinforcement			
	W30	R157	R99	R158	R114	R120	R161	R11
Baseline	29	29	29	29	29	29	29	29
Prefeeding	6	6	6	6	6	6	6	6
Baseline	26	23	26	29	23	29	30	32
VT 20 s	25	25	25	25	25	25	25	25
Baseline	30	16	16	16	25	29	22	29
Extinction	15	15	15	15	15	15	15	15
Baseline	21	26	26	26	31	31	21	21
Probes	8	8	8	8	8	8	8	8
Baseline	21	10	34	10	10	10	15	25
VT 10 s	20	20	20	20	20	20	20	20

croprocessors) and a custom-built interface. These were programmed using Borland's Turbo Pascal®, and were located in an adjacent room.

Procedure

Pretraining. Although all subjects had experimental histories, not all had experience with the stimuli used in the present experiment. Subjects were pretrained using an autoshaping procedure until they responded reliably to each stimulus. The intertrial interval was 100 s, the stimulus duration was 20 s, and reinforcement duration was 4 s. The stimulus chosen on each trial was randomly selected from the stimuli used in the experiment: For Birds W30, R157, R114, and R120 the stimuli were red on the left key, blue on the center, green on the right, and yellow randomly distributed among the three positions. For Birds R161, R99, R11, and R158 these stimuli were red on the left, green on the center, blue on the right, and white in any of the three positions. Details regarding the number of sessions in each condition and the order of conditions are presented in Table 1. Stimulus assignment, delay to reinforcement, and individual subjects' weights are in Table 2.

Following pretraining, all experimental sessions began with a 5-min period during which time the houselight was illuminated and all response keys were dark and inoperative. After this period the appropriate response key was illuminated and the experimental session began.

Baseline training. A multiple schedule with

Table 2

The FT delay to reinforcement used for the unsignaled delay and signaled delay components, stimulus assignment (color and location) for all experimental schedule components, and 80% ad lib weight (in grams) for all birds.

Bird	De- lay	Stimulus				80% ad lib
		Unsig- naled	Pre- signal	Signal	Imme- diate	
W30	3	red left	green right	yellow right	blue center	405
R157	3	green right	blue center	yellow center	red left	511
R99	3	blue right	green center	yellow center	red left	473
R158	3	green center	blue right	yellow right	red left	469
R114	8	blue center	red left	yellow left	green right	472
R120	8	blue center	green right	yellow right	red left	481
R11	8	green center	red left	yellow left	blue right	440
R161	8	red left	blue right	yellow right	green center	440

6-min components was used. The 6-min periods were timed excluding reinforcement duration. Components were separated by 2-min timeout periods, wherein the houselight was illuminated and all response keys were dark and inoperative. During each 6-min component, one of three distinct schedule types was presented: unsignaled, signaled, and immediate (see Figure 1). The stimulus correlated with each schedule was counterbalanced across subjects (with red, green, and blue stimuli) except for the signal stimulus, which was yellow for W30, R157, R114, and R120 and white for R161, R99, R11, and R158.

The unsignaled schedule was a VI 2-min schedule with an unsignaled, nonresetting delay to reinforcement. When the VI timer had elapsed, the next peck to the stimulus began a short delay until reinforcement was delivered. There was no stimulus change to signal that the terminal response had been made. Responses during this delay had no consequences. The delay varied between subjects, half receiving a 3-s delay (W30, R157, R99, and R158) and half an 8-s delay (R114, R120, R161, and R11). The signaled schedule was functionally identical to the unsignaled schedule with one exception: The delay to re-

inforcement was signaled by a change in the keylight color. The immediate schedule was a simple VI schedule. The first response after the VI timer elapsed was immediately followed by reinforcement, with no delays or stimulus changes. The immediate schedule was programmed according to either a VI 123-s or a VI 128-s schedule according to the delay of reinforcement assigned (either 3 s or 8 s, respectively) to any given subject. The unsignaled and signaled schedules were programmed according to VI 120-s schedules, and the appropriate delay interval followed completion of the schedule requirement, effectively making the schedule a VI 123 s or 128 s, accordingly. This resulted in equal reinforcement rates in all three components. All reinforcement schedules were programmed using Fleshler and Hoffman (1962) distributions. Reinforcement was 4-s access to milo.

Daily sessions consisted of 12 components, four of each schedule type. Experimental sessions typically were conducted 7 days per week, at approximately the same time of day. The order of presentation of schedule types was randomly determined, each schedule type being presented in four separate components. After baseline responding was stable, the prefeeding resistance-to-change test began. The disruption contingencies in place during each condition are described below. Subjects' weights were returned to 80% ad lib before each baseline condition, and stable baseline behavior was established prior to each resistance-to-change manipulation described below.

Resistance-to-Change Tests

Prefeeding. Over 6 consecutive days, all pigeons were fed chow approximately 1 hr prior to the beginning of each experimental session. The procedure was otherwise identical to the baseline condition. The amounts they were prefed on successive days were 20 g, 40 g, 60 g, 60 g, 60 g, and 60 g.

VT 20-s schedule of reinforcement. A VT 20-s schedule was presented during the 2-min timeout periods that separated baseline components. Time spent receiving reinforcement was not included in the 2-min timeout. All other aspects of the procedure were identical to the baseline condition. Twenty-five sessions

were conducted with the VT 20-s schedule in operation.

VT 10-s schedule of reinforcement. A VT 10-s schedule was in effect during the 2-min timeout periods between components, in the same fashion as the VT 20-s schedule condition. Twenty sessions were conducted with the VT 10-s schedule in operation.

Extinction. All schedules were placed on extinction: All events remained identical to the baseline condition except that the hopper was inoperative. During the signaled component, the signal stimulus was presented in the same manner (after a VI schedule elapsed and a terminal response), but instead of receiving reinforcement the subject was returned to the presignal stimulus.

Probes. Baseline sessions were periodically interspersed with probe sessions. Typically two baseline sessions separated each probe session. Eight probe sessions were conducted. During probe sessions three different probe tests were randomly interspersed within a baseline session, constrained in that they could not begin or end an experimental session and that a baseline component had to occur between two probe tests. Probes were presented to subjects in the same that way baseline components were presented, namely preceded and followed by timeouts. One probe presented a choice between the unsignaled and presignal stimuli, a second probe presented a choice between the unsignaled and immediate stimuli, and the third probe presented a choice between the presignal and immediate stimuli. All probe stimuli were presented in the same key positions in which they had been presented during baseline training. Probes were presented for 1 min, and responding had no consequences.

RESULTS

An alpha level of .05 was used for all statistical tests. The general strategy was to conduct an omnibus analysis of variance (ANOVA) to determine whether to proceed with tests for specific comparisons. The comparisons chosen were selected a priori and were selected to examine the role of the unsignaled delay of reinforcement on resistance to change. The results showed no chamber-related effects, so results by chamber will not be presented here.

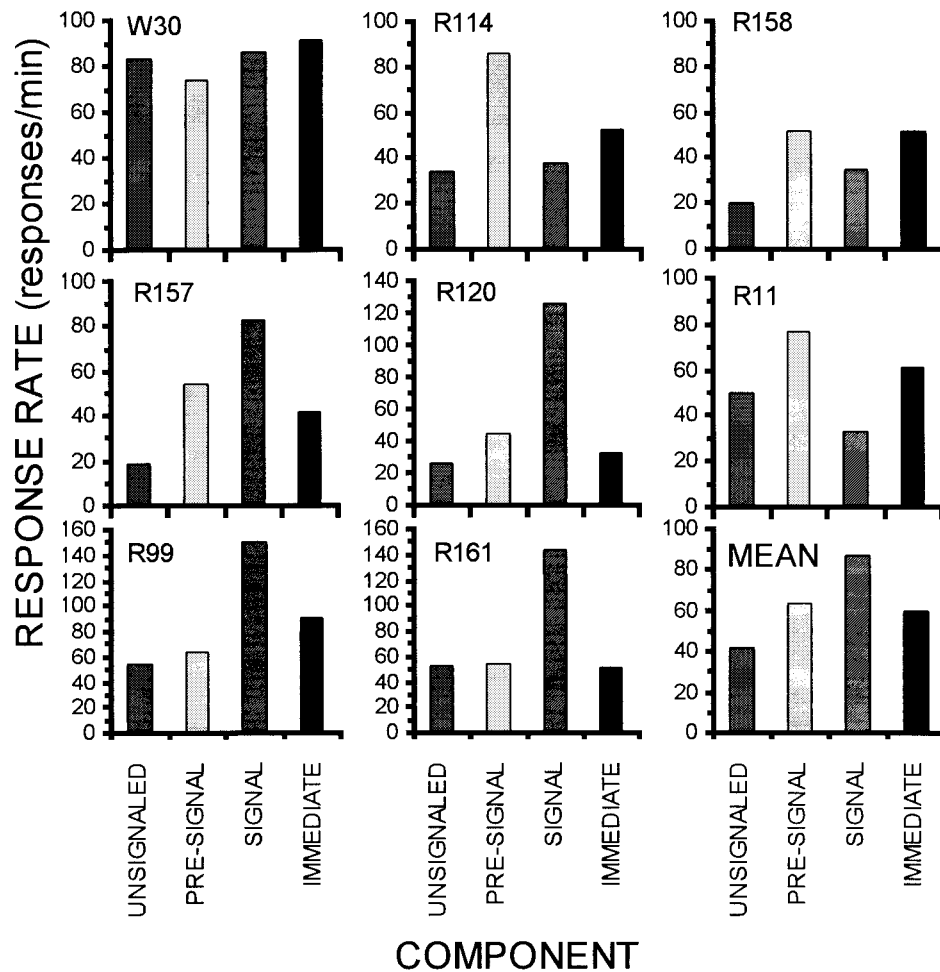


Fig. 2. Mean response rates (responses per minute) for the last five baseline sessions preceding the prefeeding phase. The bars of each panel show responding during the unsignaled component, the presignaled and signaled portions of the signaled component, and the immediate (zero-delay) component.

The mean response rates (responses per minute) during the last five baseline sessions were 42.6, 63.4, 87.1, and 59.3 for the unsignaled, presignal, signal, and immediate components, respectively. Individual-subject data are presented in Figure 2. The mean response rates for the last five baseline sessions for the unsignaled component, the presignal portion of the signaled component, and the immediate component were calculated for analysis. A 2×3 mixed design ANOVA, with delay as the between-subjects factor (3 s vs. 8 s) and component as the within-subject factor (unsignaled, presignal, immediate) revealed a significant difference between components, $F(2, 12) = 7.32$. Neither delay nor the inter-

action was significant. Two a priori specific comparisons examined the component main effect. The first compared the unsignaled component with both the presignal portion of the signaled component and the immediate component. This comparison was significant, $F(1, 12) = 14.13$. The second compared the presignal portion of the signaled component to the immediate component and was not significant.

An additional $2 \times 3 \times 4$ mixed design ANOVA, with delay as the between-subjects factor, component as the first within-subject factor, and phase (prefeeding, pre-VT 20 s, pre-VT 10 s, and preextinction) as the second within-subject factor looked for baseline re-

sponse-rate differences preceding each disruption procedure. There were no statistically significant differences among the stable mean (of the last five sessions) baseline measures. Again the only significant effect, as expected, was for component, $F(2, 12) = 16.73$. There was no main effect of delay, nor were there any significant interactions.

One possible explanation for the baseline response-rate differences could be that reinforcement rates differed among components. This possibility was tested with a 2×3 mixed ANOVA (again with delay as the between-subjects factor and component as the within-subject factor) and revealed no statistically significant reinforcement-rate differences. The mean reinforcer rates for the unsignaled, signaled, and immediate components were 0.45 reinforcers per minute, 0.46 reinforcers per minute, and 0.46 reinforcers per minute, respectively.

Responding to the signal stimulus during the first baseline condition is also presented in Figure 2. It is unclear what the prediction is for behavior in the presence of the signal stimulus, given that food is presented on an FT schedule in its presence; in other words, there is no operant contingency for responding to the key in the presence of the signal. For most subjects (W30, R157, R99, R120, and R161) the signal maintained a higher response rate compared to the presignal stimulus. For the remaining 3 subjects (R158, R114, and R11) responding during the signal was reduced relative to the presignal stimulus. A 2×2 mixed design ANOVA with delay as the between-subjects factor and stimulus (presignal vs. signal) as the within-subject factor was conducted to compare the response rate in the presence of the presignal stimulus to the response rate in the presence of the signal stimulus. The analysis showed no main effects of delay or component, nor was there a significant interaction.

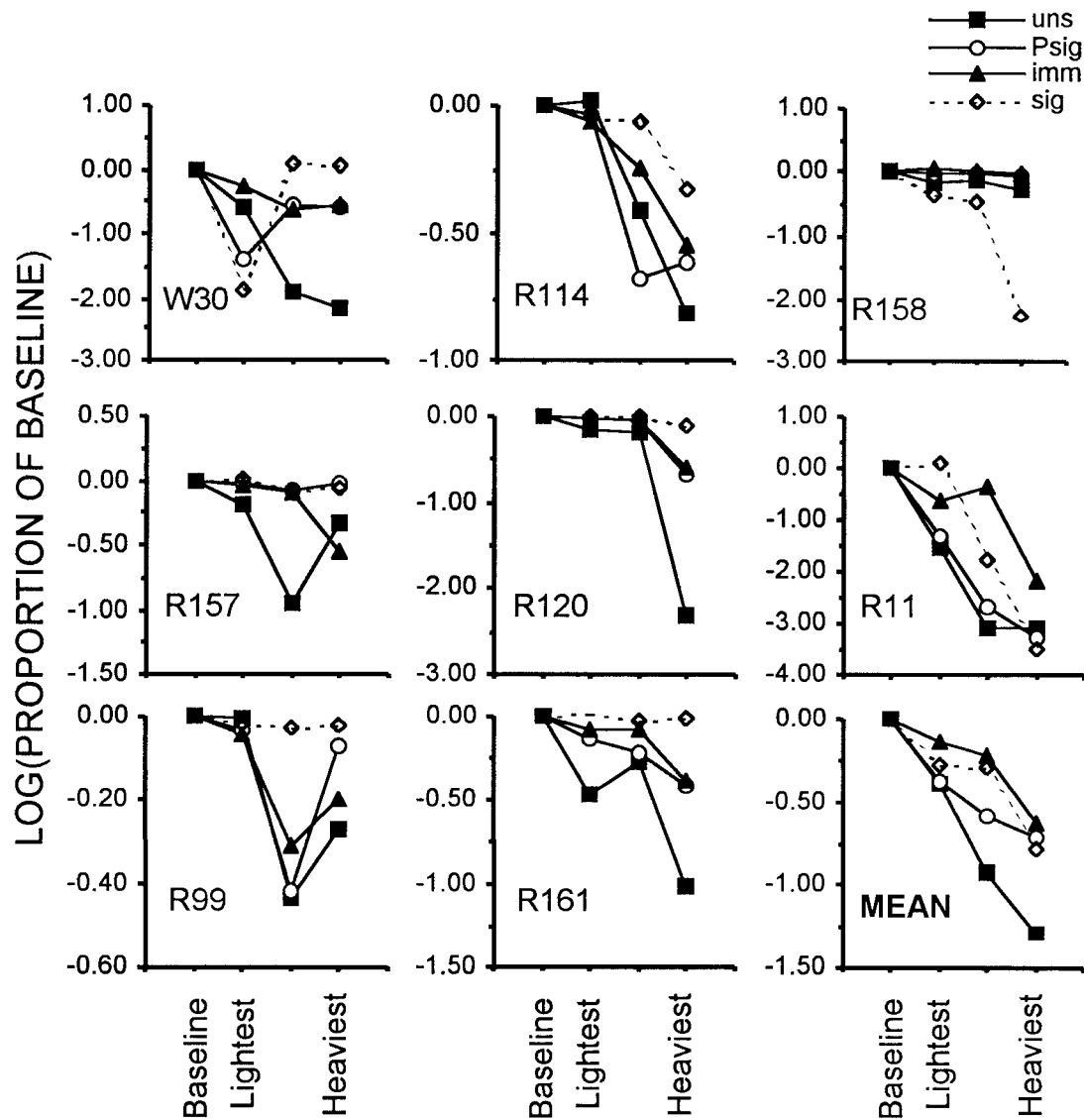
Slopes were used to assess resistance to change for the prefeeding condition. There was no reason to assume that session was perfectly correlated with amount consumed, except that there were increasing amounts of food given to subjects preceding experimental sessions. Consistent with an operational definition of satiation as body weight, the data from the prefeeding sessions were

ranked and analyzed in terms of subjects' precession weights.

Once the data were ordered according to precession weights, they were transformed to a proportion-of-baseline measure to equate all three schedules, and finally the logs of those resulting proportions were calculated. The results from the prefeeding sessions are plotted in Figure 3, according to the log proportion of baseline over all prefeeding sessions. Regression lines were fit to these data, using a least squares method. Because $\log(0)$ is undefined, these data points were treated as if the subject had made one response [i.e., 1 response per 24 min or 0.0417 responses per minute; see Tukey, 1977, for a discussion of handling $\log(0)$ data]. The subsequent analyses used the slopes as the dependent variable, and are presented in Table 3. An analysis of the slopes revealed a significant effect of schedule, $F(2, 12) = 5.00$, and both delay and the interaction were nonsignificant. Two a priori comparisons examined the slope differences. The first comparison compared the unsignaled schedule slope to both the presignal schedule and immediate schedule slopes. This comparison was significant, $F(1, 12) = 9.99$, indicating a steeper slope for the unsignaled schedule relative to both the presignal and immediate schedule slopes. The second comparison, between the presignal schedule slope and the immediate schedule slope, revealed no significant difference.

The mean response rates during the last five baseline sessions preceding the VT 20-s schedule disrupter were 33.8, 62.7, 74.8, and 54 for the unsignaled, presignal, signal, and immediate components, respectively. The mean response rates during the last five baseline sessions preceding the VT 10-s schedule disrupter were 36.2, 63.1, 49.4, and 54.4 for the unsignaled, presignal, signal, and immediate components, respectively.

Because responding in both VT phases did not decrease in a linear fashion, slope calculations for the VT phases are not included here. Instead $\log(B_x/B_o)$ was calculated (see Figure 4), where B_x is the response rate during disruption by the added VT schedule and B_o is the response rate during the baseline phase immediately preceding disruption. This analysis used the mean of the last 10 days of baseline and the last 10 days of the respective VT phases in an attempt to capture sta-



TWO-SESSION BLOCKS (arranged by pre-session weight)

Fig. 3. Effects of prefeeding on schedule performance expressed as logarithms of the proportion of baseline. The baseline used was the mean of the last five baseline sessions preceding the prefeeding condition. The data were arranged according to each subject's pre-session weight, from lightest to heaviest, collapsed into two-session blocks. Included are responding during the unsignaled component, during both the presignal and signal portions of the signaled component, and during the immediate component. Note that the ordinate differs across subjects.

ble, asymptotic responding for both the baseline and the VT conditions.

A 2×4 mixed design ANOVA examined the $\log(B_v/B_o)$ data (Table 4) for each VT condition separately, with delay (3 s and 8 s) as the between-subjects factor and compo-

nent (unsignaled, immediate, presignal, and signal) as the within-subject factor. The ANOVA for the VT 20-s condition revealed a significant effect of component, $F(3, 18) = 4.64$, but no significant effect of delay and no significant Component \times Delay interaction.

Table 3

Slopes calculated from linear fits of the log of the proportion of baseline data for the prefeeding disruption phase. Data were ranked (prior to fitting) according to presession weight (rather than the actual temporal sequence). Note that the presignaled component data represent responding during the presignal portion of the signaled component and do not include responding in the presence of the signal, which is presented in a separate column.

Delay	Subject	Component			Immediate
		Un-signaled	Presignal	Signal	
3	W30	-0.488	-0.053	0.135	-0.119
3	R157	-0.126	-0.005	-0.016	-0.117
3	R99	-0.079	-0.041	-0.003	-0.050
3	R158	-0.031	-0.009	-0.438	-0.012
8	R114	-0.133	-0.107	-0.052	-0.178
8	R120	-0.381	-0.113	-0.017	-0.097
8	R161	-0.165	-0.079	-0.004	-0.070
8	R11	-0.552	-0.559	-0.639	-0.388

Contrasts compared the immediate component with each of the other three components individually. This test found no significant difference even though the overall F test was significant for component.

The same 2×4 mixed design ANOVA was used for the VT 10-s condition, and this also revealed a significant effect of component, $F(3, 18) = 6.52$, no significant effect of delay, and no significant Component \times Delay interaction. Again, contrasts compared the immediate component with each of the other three components individually. Only one significant difference, $F(1, 6) = 8.12$, was seen between the unsignaled component and the immediate component. All other contrasts were not statistically significant.

The mean response rates during the last five baseline sessions preceding the extinction manipulation were 28.4, 60.2, 59.5, and 53.6 for the unsignaled, presignal, signal, and immediate components, respectively. Lines were fitted to the log of the proportion of baseline data, and the slopes were calculated by including instances when responding went to zero. The results from the extinction sessions are plotted in Figure 5, according to the log proportion of baseline over all extinction sessions. The analysis was repeated by fitting lines to the data up to zero; the results from the statistical analysis revealed the same pattern of results and are not, therefore, pre-

sented here. Again, because $\log(0)$ is undefined, sessions in which no responses were made were treated as if one response had been made. The resulting slopes are reported in Table 5. Note that the slopes in Table 5 were calculated using individual extinction sessions and that the data presented in Figure 5 are combined into blocks of three sessions.

The ANOVA of the delay main effect was not significant. There was a significant effect of component, $F(2, 12) = 14.00$, and specific comparisons revealed no significant difference between the unsignaled component pitted against both the presignal component and the immediate component. There was a significant difference, $F(1, 12) = 24.27$, between the presignal stimulus and the immediate stimulus (responding was higher to the presignal stimulus, probably because the signal stimulus contingency was maintained during extinction, thus maintaining the conditioned reinforcement contingency between the presignal stimulus and the signal). The interaction between delay and component was not significant.

The results from the probe tests are presented in Figure 6. Three two-tailed t tests using an alpha level of .05 were conducted to test whether the resulting preference data were significantly different from .50 (chance responding). The mean preference for the probe comparison involving a choice between stimuli correlated with the unsignaled schedule of reinforcement and the stimulus preceding the signal in the signaled schedule of reinforcement (the presignal stimulus) was .10, significantly different from .50, $t(7) = 5.46$. This indicates preference for the stimulus correlated with the presignal schedule. Preference in the probe test containing the stimuli correlated with the unsignaled and immediate schedules was .05, showing preference for the stimulus correlated with the immediate schedule. This was also significantly different from .50, $t(7) = 17.32$. The comparison between the presignal stimulus and the immediate stimulus was .35, which was not statistically significantly different from .50, $t(7) = 1.17$.

DISCUSSION

This study demonstrated, using a procedure that manipulated response-reinforcer

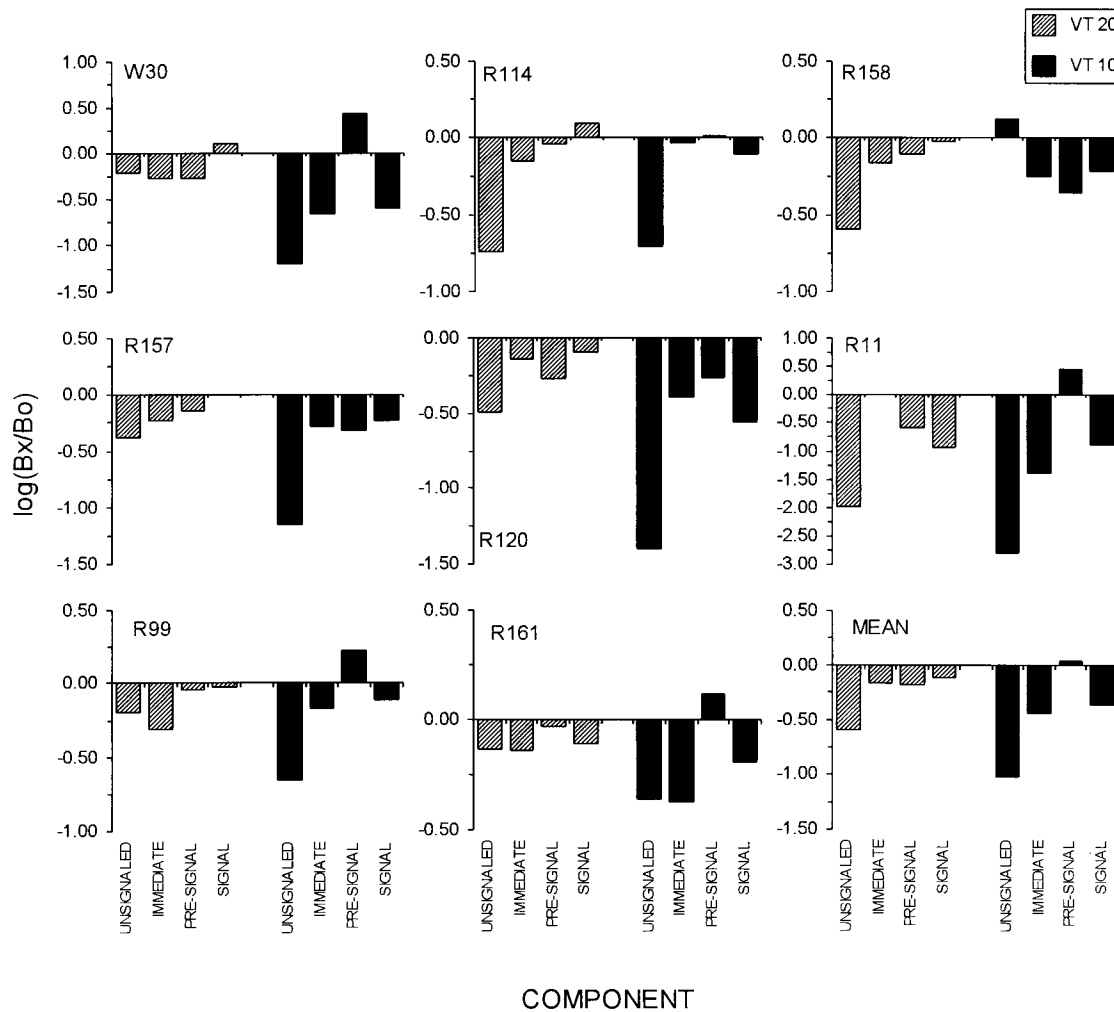


Fig. 4. Using the mean of the last 10 baseline sessions and the last 10 days of the VT 20-s and VT 10-s disruption conditions, the $\log(B_x/B_0)$ was calculated (B_x is the response rate during disruption by the added VT schedule, and B_0 is the response rate during the baseline phase immediately preceding disruption). This analysis used the mean of the last 10 days of baseline and the last 10 days of the respective VT phases in an attempt to capture stable, asymptotic responding for both the baseline and the VT conditions. The proportion change during the unsignaled component, during both the presignal and signal portions of the signaled component, and during the immediate component are included.

contiguity while maintaining Pavlovian contingencies, that resistance to change is not solely determined by Pavlovian contingencies. The results, with the exception of the extinction manipulation, showed that the unsignaled delay schedule, the schedule with a degraded response–reinforcer contiguity, was always less resistant to change relative to both the signaled and immediate schedules. This contradicts the prediction made by Nevin (1992) that resistance of responding under the unsignaled delay schedule and the im-

mediate schedule should be equal because rate of reinforcement was the same for the two components (as was the amount of time spent in the presence of the unsignaled and immediate components). The Pavlovian interpretation of momentum predicts that resistance to change for the two components should be identical because the stimulus–reinforcer contingencies are identical.

The other prediction implied by the Pavlovian interpretation of behavioral momentum is that responding in the presence of the

Table 4

Baseline and VT condition data were transformed to $\log(B_x/B_o)$, where B_o is the mean response rate during the last 10 baseline sessions and B_x is the mean response rate during the last 10 VT sessions. The data presented separate presignal and signal responding for the signaled component.

Subject	Component							
	VT 20-s condition				VT 10-s condition			
	Unsignaled	Presignal	Signal	Immediate	Unsignaled	Presignal	Signal	Immediate
W30	-0.21	-0.27	0.11	-0.28	-1.20	-0.60	-0.66	0.43
R157	-0.39	-0.15	0.01	-0.23	-1.16	-0.24	-0.28	-0.32
R99	-0.19	-0.04	-0.03	-0.31	-0.65	-0.11	-0.17	0.22
R158	-0.60	-0.11	-0.02	-0.16	0.13	-0.22	-0.25	-0.35
R114	-0.74	-0.05	0.10	-0.16	-0.71	-0.10	-0.03	0.01
R120	-0.49	-0.27	-0.10	-0.14	-1.40	-0.56	-0.39	-0.26
R161	-0.14	-0.03	-0.11	-0.14	-0.36	-0.20	-0.37	0.12
R11	-1.98	-0.59	-0.94	0.00	-2.81	-0.90	-1.39	0.46

presignal stimulus portion of the signaled component should be the least resistant to change. This was generally not supported by the data, which showed that differences in resistance to change were not a function of reinforcement rate: That was the same for all three schedule types.

The results from the prefeeding manipulation revealed a significant difference in slope for the unsignaled component compared to both the presignal portion of the signaled component and the immediate component. This characterizes both the immediate component and the presignal portion of the signaled component as generating responding that was more resistant to change than the unsignaled schedule, contradicting the Pavlovian view of momentum.

The results from the conditions with the VT schedule were not suited to analysis of the slopes, because the majority of the decrease in responding occurred primarily in the first session after the VT schedule was introduced. Therefore the data were analyzed by examining stable behavior in both the baseline and the VT conditions, an analysis suggested by Harper and McLean (1992) and McLean and Blampied (1995), who discussed potential differences between the immediate effects of disrupters and the long-term steady-state effects. It is possible that the overall amount of change could be quite different, whereas the rate of change for both schedules was identical. In other words, the two behaviors could approach their respective new asymptotes at the same rate, but the asymptote of the weak-

er behavior might be proportionally less than the asymptote of the stronger behavior. The data were transformed by taking the log ratio of asymptotic responding during the VT condition (B_x) to the asymptotic level during the preceding baseline condition (B_o). The finding was generally consistent with those from the prefeeding condition, showing the unsignaled component to be the most sensitive (i.e., most changed) to the added free-food contingency (see Figure 4).

Interpreting the results from the extinction phase is slightly more complicated than interpreting the prefeeding data and the VT data, but those data still do not support the prediction made by the Pavlovian view of behavioral momentum. In the extinction condition, responding in the presence of the presignal stimulus was the most resistant, and responding in the presence of the unsignaled and immediate components was statistically identical. Note that visual inspection of the data suggests that the calculated slopes do not accurately illustrate the decreases in behavior. Typically the data points from the unsignaled schedule were equal to or below those from the immediate schedule. Responding to the presignal stimulus in the signaled component was seemingly maintained by a conditioned reinforcement contingency, in that the signal was still presented on a VI schedule during extinction testing, thus functioning to reinforce responding during the presignal portion of the signaled schedule.

The probe results agree with the resistance-to-change results, and support the notion

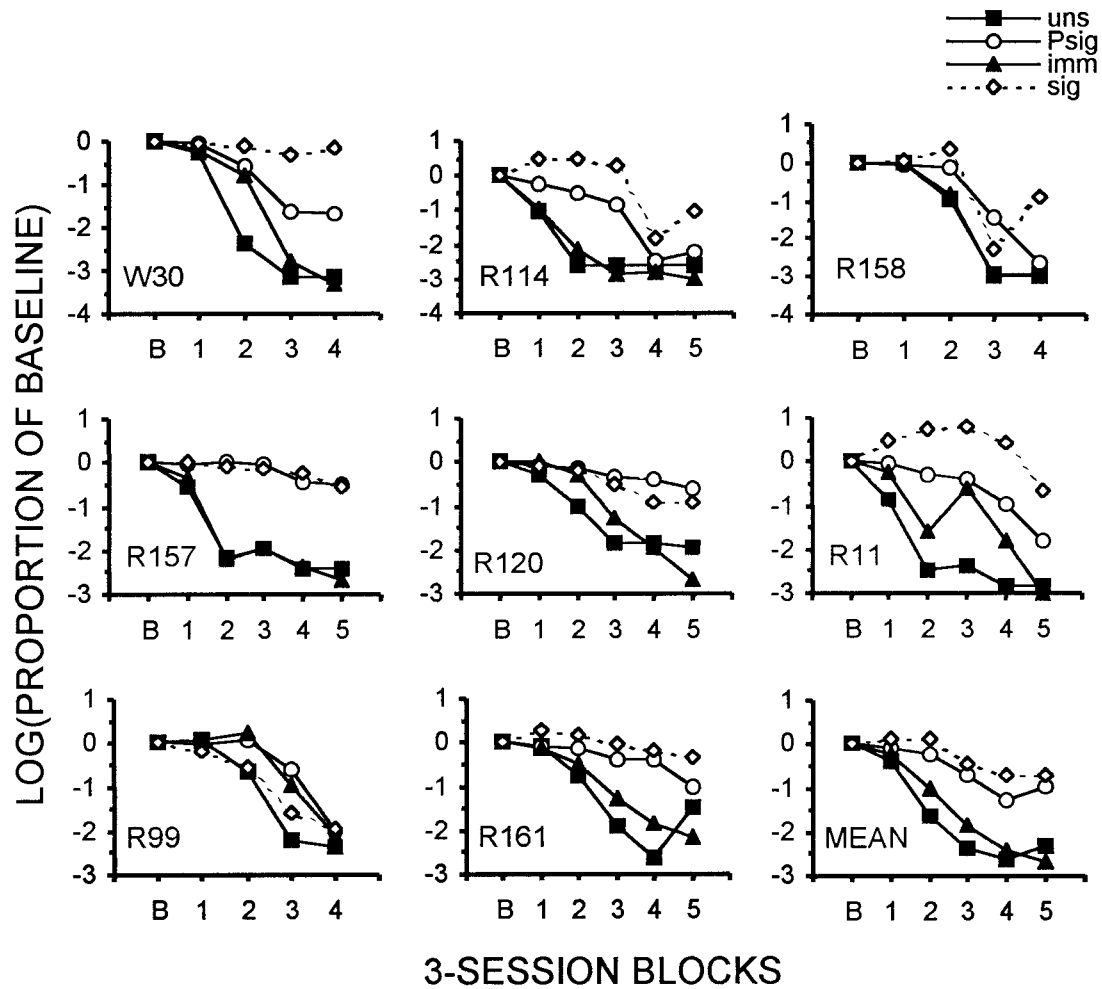


Fig. 5. Effects of extinction on schedule performance, expressed as logarithms of the proportion of baseline. The baseline used was the mean of the last five baseline sessions preceding the extinction condition. Responding during the unsignaled component, during both the presignal and signal portions of the signaled component, and during the immediate component are included. The data were collapsed into three-session blocks.

that resistance to change and preference are assessing the same thing, namely response strength. The results show that the stimulus correlated with the unsignaled schedule of reinforcement was clearly the least preferred, regardless of the alternative. This finding is in concordance with those of Grace et al. (1998), who found similar preference results using a concurrent-chains procedure, in which they assessed preference by comparing an immediate alternative with an alternative with a 3-s unsignaled delay. The probe preference test results from the stimuli correlated with the presignal portion of the signaled schedule of reinforcement and the stimulus

correlated with the immediate schedule of reinforcement were more ambiguous, with some subjects preferring the presignal stimulus and others preferring the immediate stimulus.

The fact that there was no reliable difference between the presignal stimulus and the immediate stimulus in probe tests is perhaps attributable to the varying functional role of the signal across subjects. Response rates in the presence of the signal varied, with most subjects showing a relative increase in rate. Several subjects, however, showed decreases in response rate during the signal. It is unclear what determined response rate in the

Table 5

Slopes calculated from linear fits of the log of the proportion of baseline response-rate data for the extinction disruption phase. Note that the response-rate data for the presignal schedule do not include responding in the presence of the signal, which is presented in a separate column. The means of the last 10 baseline sessions and all extinction phase sessions were used to calculate slopes, including sessions in which no responding occurred. Omitting sessions in which no responding occurred had no effect on the conclusions.

Delay	Subject	Component			
		Unsig- naled	Presignal	Signal	Immedi- ate
3	W30	-0.313	-0.189	-0.022	-0.345
3	R157	-0.161	-0.041	-0.038	-0.174
3	R99	-0.309	-0.177	-0.232	-0.221
3	R158	-0.351	-0.254	-0.200	-0.365
8	R114	-0.140	-0.190	-0.148	-0.190
8	R120	-0.140	-0.040	-0.074	-0.221
8	R161	-0.159	-0.066	-0.043	-0.175
8	R11	-0.162	-0.138	-0.065	-0.185

presence of the signal, but it is not uncommon to see this range of variability (Davison, Sheldon, & Lobb, 1980; Williams, 1989). Davison et al. attributed the differences to subject-idiosyncratic history effects. The lack of a response requirement should reduce behavior, whereas the short delays between the terminal response and the delivery of reinforcement should increase the value of the signal.

The role of the signal in the signaled component. The findings regarding the relationship between the presignal stimulus and the signal stimulus from the present study differ from those found by Nevin et al. (1981), who proposed that an initial-link stimulus should be weaker (less resistant) because of its distance from the primary reinforcer, especially if the signal stimulus is not acting as a conditioned reinforcer. It is likely that the short fixed-time delays used in the present experiment served as strong conditioned reinforcers, maintaining initial-link (presignal) responding, whereas the long delays used by Nevin et al. (random-interval 40-s schedules for both the initial and terminal links) made the terminal links much weaker conditioned reinforcers (if they even served as conditioned reinforcers), thus not maintaining initial-link responding. Leung and Winton (1988) provide support for this argument: They presented pigeons with concurrent-chains schedules of reinforcement. The initial links were VI 60-s

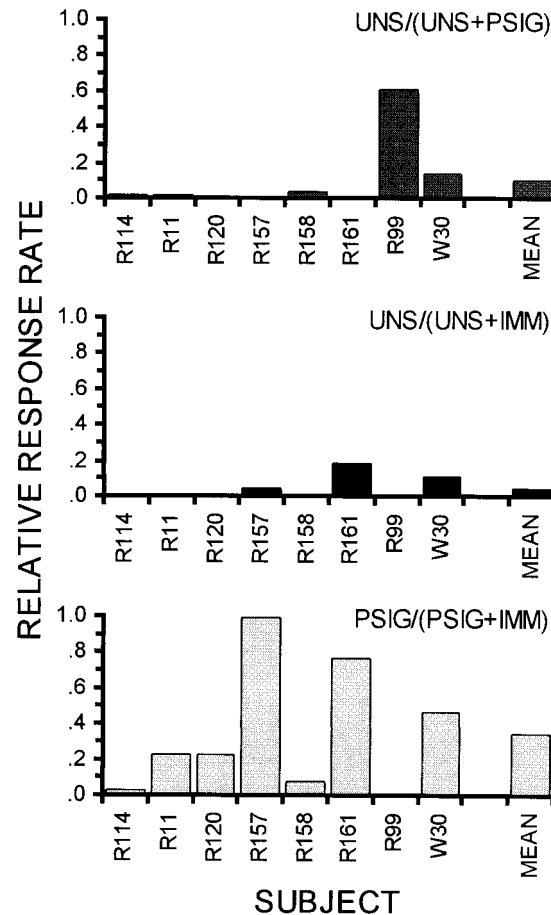


Fig. 6. Relative response rates during extinction probe tests. The top panel shows the results from the probe test in which subjects were given a choice between the stimulus correlated with the presignal portion of the signaled component and the stimulus correlated with the unsignaled component. The middle panel shows the mean results from the probe test in which subjects were presented with a choice between the stimulus correlated with the immediate component and the stimulus correlated with the unsignaled component. The bottom panel represents the results from the probe test in which subjects were given a choice between the stimulus correlated with the immediate component and the stimulus correlated with the presignal portion of the signaled component.

schedules and the terminal links were either fixed-interval (FI) 15-s or FI 30-s schedules. One terminal link was a simple FI schedule, and the other was segmented by a stimulus change. When the segmentation ratio was 1:14 (i.e., 1 s of Stimulus 1 followed by 14 s of Stimulus 2), subjects preferred the simple FI terminal link over the segmented terminal

link. The same was true when the segmentation ratio was 1:1 (i.e., 7.5 s of Stimulus 1 followed by 7.5 s of Stimulus 2), a ratio comparable to the chain used by Nevin et al. As the segmentation ratio in Leung and Winton's study approached 14:1 (a ratio similar to the ratio in the present study), subjects' preference moved toward indifference, and in a few cases reversed (although only slightly).

Clearly, resistance to change is not dependent only on the rate of reinforcement in the presence of the discriminative stimulus. This experiment, combined with a few additional studies (Grace et al., 1998; Lattal, 1989; Nevin, 1974), suggest that response-reinforcer contiguity does play a role in resistance to change, with lower response rates correlated with greater resistance to change. Grace et al. attempted to reconcile the idea that Pavlovian contingencies determine resistance to change with the data, suggesting several possible factors that affected resistance to change, such as differential response topographies, inhibitory conditioning for the unsignaled stimulus, and degraded Pavlovian conditioning for the unsignaled stimulus. Additional research is needed to investigate what role these factors have in influencing resistance to change.

Regardless, these findings are contrary to Nevin's (1992) assertion that response rate has no real influence on resistance to change. The relationship between response rate and response strength is argued to be an operant response-reinforcer relationship. Any changes in response rate could simply reflect performance or training differences, not actual differences in response strength. A DRL schedule of reinforcement maintains low rates of responding because the response contingency demands that subjects respond slowly to earn reinforcers, but does not necessarily provide any information about the actual strength of behavior. Response strength is, in turn, a function of the Pavlovian relationship between the discriminative stimulus and the reinforcer (Nevin, 1984, 1992; Nevin, Smith, & Roberts, 1987). Rate of reinforcement in the presence of a stimulus is the crucial factor that determines response strength: Increases in rate of reinforcement result in increased resistance to change.

The discrepancy between the present re-

sults, showing an effect on resistance to change as a function of manipulating the operant contingency, and the results of Nevin et al. (1990), who reported that operant contingencies had no effect on resistance to change, needs to be briefly addressed. The solution is most likely the location of the manipulation of the operant contingency. Nevin et al. manipulated the operant contingency in the nontarget component, thus maintaining both the operant contingency and the Pavlovian contingency for the target component. The present study directly manipulated the operant relationship in the target component, thus directly affecting the relationship between behavior and reinforcement.

Nevertheless, the common finding is that responding under richer reinforcement schedules is less affected, relative to leaner reinforcement schedules, when a resistance-to-change manipulation is imposed. This is contrary to conventional notions, particularly to the traditional view of the decline of responding during extinction. Previously it was assumed (because response rate was the accepted measure of response strength) that leaner schedules were more resistant to extinction than richer schedules, as measured by the absolute decrease in responding. Resistance to change takes an innovative approach, showing precisely the opposite results when the measure was not absolute decreases in rate, but instead changes in rate relative to the baseline response rate (Nevin, 1988). With this analysis, richer schedules arguably have more strength because they have greater resistance to change as a proportion of baseline.

Despite major success in previous research, behavioral momentum theory faces several challenges before it can be accepted as a general theory of response strength. There is already evidence (e.g., Cohen, Riley, & Weigle, 1993) that rate of reinforcement does not predict resistance to change in simple schedules. This is problematic for resistance to change, and therefore behavioral momentum, because this limits generalizability and questions momentum as an adequate theory of response strength. The present experiment exposed another weakness in behavioral momentum theory by investigating the role of response-reinforcer contiguity using delay of reinforcement and the relationship be-

tween resistance to change and preference, demonstrating that the Pavlovian relationship is not the sole determinant of resistance to change.

Additional research must be conducted to more fully understand the role of conditioned reinforcement and its relationship to resistance to change. The present study does not directly address how conditioned reinforcement affects resistance to change, because the signal was always presented throughout all resistance-to-change manipulations. The extinction condition does suggest that the signal was functioning as a conditioned reinforcer, because behavior in the presence of the presignal stimulus was more resistant to change than was responding to both the unsignaled and immediate schedules. This finding is not unexpected. Williams, Ploog, and Bell (1995) found that when responding on a three-link chain schedule was extinguished, the presence of later links (closer to primary reinforcement) of the chain slowed the rate at which responding on earlier links was extinguished. Regardless, the present study does suggest that the operant relationship plays an important role in determining resistance to change.

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